Reliability of the diffusion indexes derived from fast diffusion kurtosis imaging

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Introduction

Diffusion kurtosis (DK) imaging [1] is an extended diffusion MR imaging technique that permits evaluation of diffusion heterogeneity, a common characteristic of biological tissue that causes non-Gaussian diffusion. As compared with conventional diffusion imaging, DK imaging requires more diffusion encoding steps (i.e., longer scan time) and more complex model fitting (i.e., longer post-processing time). Jensen and coworkers [2] recently proposed a fast DK imaging method based on 3-b-value acquisition and closed-form expressions (see Eq. [1]). Although time efficient, the method may be prone to extreme variability of a single data point (as compared with to relatively time-consuming fitting over multiple data points). In this study, we investigated the variability of the indexes derived with fast DK imaging in the context of signal-to-noise ratio (SNR). The sensitivity of the indexes was compared with the corresponding indexes derived from the stretched exponential model (SEM) imaging [3], another extended diffusion imaging technique.

Materials and Methods

The institutional review board approved this study. Ten brain tumor outpatients were included and each provided written informed consent before participation. MR imaging was conducted on a 3T scanner (Tim Trio, Siemens, Erlangen) using the body coil transmitter and a 12-channel phased-array head coil receiver. Diffusion imaging was based on the twice-refocused spin-echo echo-planar readout and following parameters: field-of-view = 20 cm, 16 slices, voxel size = 2x2x4 mm^3, TR = 3 s, TE = 94 ms. Diffusion encoding was applied along 30 directions (3 averages, b-value = 0, 850, 1700 s/mm^2) for DK imaging and 3 orthogonal directions (8 averages, b-value = 0, 400, 550, 700, 850, 1100, 1400, 1700 s/mm^2) for SEM imaging. For fast DK imaging, diffusion coefficient (D) and diffusion kurtosis coefficient (K) were derived by Eqs [1] and [2] in which ADC_1 and ADC_2 are the apparent diffusion coefficients calculated using the b-value pairs of (0, b_1 = 850) and (0, b_2 = 1700), respectively. For SEM imaging, distributed diffusion coefficient (DDC) and stretching parameter (α) were derived by Eq [3] in which S_0 is the MR signal in the absence of diffusion encoding. K and α both characterize diffusion heterogeneity but are oppositely related [3]. Diffusion indexes of patients were compared at four regions of interest: peritumoral edema (ED), normal appearing white matter (NAWM), globus pallidus (GP), and thalamus (TH).Variability of D and K was evaluated at varied SNR levels by computer simulations (1000 samples for each condition) in terms of coefficient of variation (CV).

$$D = \frac{b_2 ADC_1 - b_1 ADC_2}{b_2 - b_1} \quad [1]$$

$$K = \frac{6(ADC_1 - ADC_2)}{(b_2 - b_1)D^2} \quad [2]$$

$$\frac{S(b)}{S_0} = exp\left(-(b \cdot DDC)^{\alpha}\right) \quad [3]$$

Results and Discussion

As shown in Fig 1, CV decreases for both D and K when SNR increases. D is more robust against noise than K. K has low reliability when diffusion heterogeneity is low (e.g., K = 0.4). Otherwise, a minimum SNR_{b1700} of ~30 is required to achieve 30% variability. The overall SNR_{b1700} is ~40 in our experimental data. Fig 2 shows that D and DDC are parallel except D appears overestimated in globus pallidus where diffusion has high non-Gaussianity as indicated by K and α (data not shown). In summary, fast DK imaging provides diffusion indexes of reasonable precision although the reliability should be considered in the context of SNR. The SNR requirement revealed in our data also suggests that adequate SNR is critical for diffusion kurtosis tensor.

Fig 1

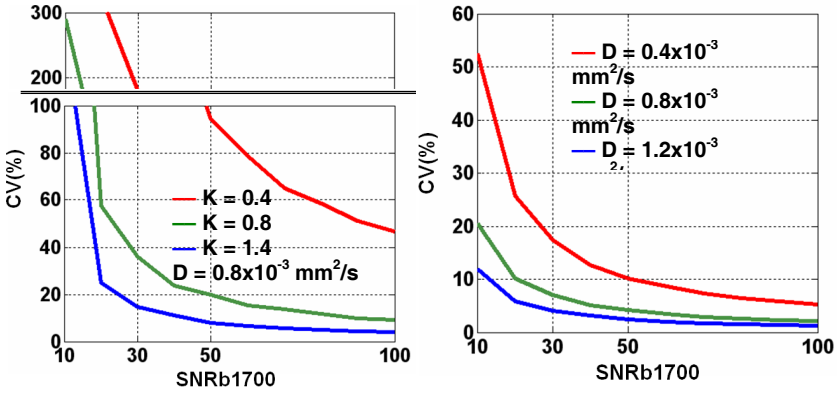
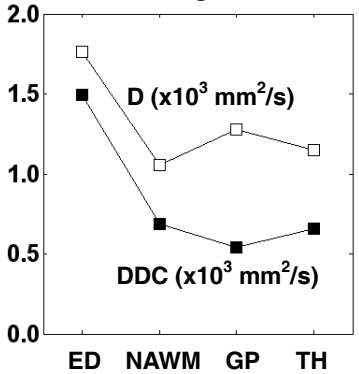


Fig 2



References

1. Jensen JH et al. MRM 2005;53(6):1432-40.
2. Jensen JH et al. ISMRM 2009:1403.
3. Bennett KM et al. MRM 2003;50(4):727-34.